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US ARMY
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HELICOPTER STRUCTURAL INTEGRITY PROGRAM (HSIP)

Volume I - Structural Test Requirements Specification

J. Martin, J. Fila, and D. Reisdorfer

Bell Helicopter Textron Inc.
Fort Worth, TX 76101

July 1990

Final Report for Period November 1988 - December 1989

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Prepared for

AVIATION APPLIED TECHNOLOGY DIRECTORATE
US ARMY AVIATION SYSTEMS COMMAND
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AVIATION APPLIED TECHNOLOGY DIRECTORATE POSITION STATEMENT

This report provides a comprehensive draft structural test requirements specification for U.S. Army rotorcraft. The report includes ground test requirements for metallic and composite airframe and dynamic structural components applicable to a wide range of rotorcraft and configurations (helicopter, tilt rotor, compound, etc.) and missions. The test requirements defined in this draft specification address safe-life, damage tolerance and total life design methodologies. Special emphasis is placed on establishing and verifying the structural reliability of rotorcraft structural components.

This effort is a part of the U.S. Army Aviation System Command's Helicopter Structural Integrity efforts and will be used as the basis for the establishment of future Aeronautical Design Standards and Specifications governing structural test requirements of rotorcraft.

Mr. Barry Spigel, Aeronautical Systems and Technology Division, Structures Technical Area, served as project engineer for this effort.

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13. ABSTRACT *(Maximum 200 words)*
This Structural Test Requirements Program is designed to provide the necessary ground test requirements to support the overall HSIP objectives. The Structural Test Requirements portion of the HSIP covers the ground tests which are required during the design development and qualification of rotary-wing/VTOL aircraft. The structural test requirements specification addresses composite and metallic components. Through a comprehensive survey of existing specifications and related documents for structural testing of rotary-wing/VTOL aircraft, key test technology elements such as static, fatigue, durability and damage tolerance have been assessed for suitability to future aircraft systems, and evaluated for applicability into the test requirements specification. In cases where no adequate test requirements exist, this program has developed those requirements. A draft test specification was developed and presented to various representatives of the helicopter industry and government agencies at a Government/Industry Forum. Comments received from the forum participants were evaluated and incorporated, if appropriate, into a final revised specification.

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INTRODUCTION

This final technical report has been prepared by Bell Helicopter Textron Incorporated (BHTI) for the Helicopter Structural Integrity Program (HSIP), Structural Test Requirements. This volume contains the final revised Structural Test Requirements Specification. Volume II documents the development of the specification, including supporting rationale.

The Army's HSIP will establish a set of formal regulations, standards and specifications to ensure that structural integrity receives attention early in the concept definition phase and is an integral part of the design, testing, and operation of an aircraft system. HSIP will require the development of structural design criteria for Army rotorcraft which define the design requirements and design factors for given missions, classes and configurations of the aircraft. Additional specifications will be written to define the structural requirements for the materials and processes qualification, the analysis and test of the design, and the operational data acquisition and data management requirements for a weapon system. Also, a structural integrity verification program will assess the structural integrity specifications and procedures through the design, test, and in-service monitoring of selected helicopter components.

This Structural Test Requirements Program is designed to provide the necessary ground test requirements to support the overall HSIP objectives. In general, the Structural Test Requirements portion of the HSIP covers the ground tests which are required during the design development and qualification of rotary-wing/VTOL aircraft. Flight test requirements are not included in this program.

The purpose of the HSIP Structural Test Requirements Program is to develop a comprehensive Structural Test Requirements Specification for Army rotory-wing/VTOL aircraft. The structural test requirements specification addresses composite and metallic airframe components, and composite and metallic dynamic components separately.

Through a comprehensive survey of existing specifications and related documents for structural testing of rotary-wing/VTOL aircraft, key test technology elements such as static, fatigue, durability and damage tolerance have been assessed for suitability to future aircraft systems, and evaluated for applicability into the test requirements specification. In cases where no adequate test requirements exist, this program has developed those requirements.

A draft test specification was developed and presented to various representatives of the helicopter industry and government agencies at a Government/Industry Forum. Comments received from the forum participants were evaluated and incorporated, if appropriate, into a final revised specification.

HELICOPTER STRUCTURAL INTEGRITY PROGRAM

ROTORCRAFT STRUCTURAL TEST REQUIREMENTS, GROUND

1. SCOPE

1.1 Test Requirements. This document presents a comprehensive set of structural ground test requirements for all types of rotary-wing/VSTOL aircraft (referred to herein as "rotorcraft"). Due to the potential wide variety of design philosophy, criteria requirements, and configurations, it is not the intent of this specification that all of the requirements in Sections 3.2, 3.3, and 3.4 be applicable for every acquisition program. Specific tests contained herein should be selected that meet the objectives of the acquisition program.

1.2 Guidance and Usage. This document is intended to provide guidance for rotorcraft procurement programs, to serve the procurement agency in the development of specific system specifications, and to serve the contractor in developing a viable structural test program. At the program outset, consideration should be given by the procuring agency to the need for special additional tests, such as landing gear drop tests, crashworthiness tests (static and dynamic), bird strike tests, pressurization tests, ballistic damage tests, high energy laser damage tests, and lightning strike protection tests.

The contractor shall prepare an airworthiness qualification specification (AQS) which will identify all of the applicable ground test elements, which are selected from this test requirements specification, in order to meet the particular objectives of the acquisition program. The AQS will also contain rationale and basis for selection of the tests in support of the system design criteria. The structural integrity of the rotorcraft and its components may be verified by analysis, test, or a combination of test and analysis, as proposed by the contractor. The structural integrity program shall verify the ultimate load capability, structural life, and structural reliability of the rotorcraft. Consideration should be given to the extent of test requirements based upon program elements such as "lead-the-fleet" or "flight safety parts," redundancy of design, inspection intervals, and fail-safe or safe-life design philosophies. The contractor should propose the most economical and schedule-effective approach to the overall structural test program as affirmed by substantiating data.

Additional considerations that should be taken into account when selecting the applicable test requirements are as follows:

a. Life Assurance Methodologies Approach. Test requirements can only be defined relative to the approach used for life determination. These approaches will differ for various structures and are highly dependent on material/component failure modes and the anticipated/verified load spectrum (low, high cycle or both). The contractor shall include the chosen life assurance methodologies into the AQS which describes the proposed method of repeated loads qualification and the degree of testing and analysis necessary for qualifying each major component.

b. Reliability. Depending upon the reliability requirements of a specific acquisition program, the contractor may have to define a reliability methodology to meet those requirements. The type of tests and number of test articles/specimens need to be selected to support the chosen methodology.

1.3 Program Implementation. The determination as to whether or not a particular test method/type is to be utilized is made through a stepwise procedure involving the contracting agency and the contractor, as shown in Figure 1.

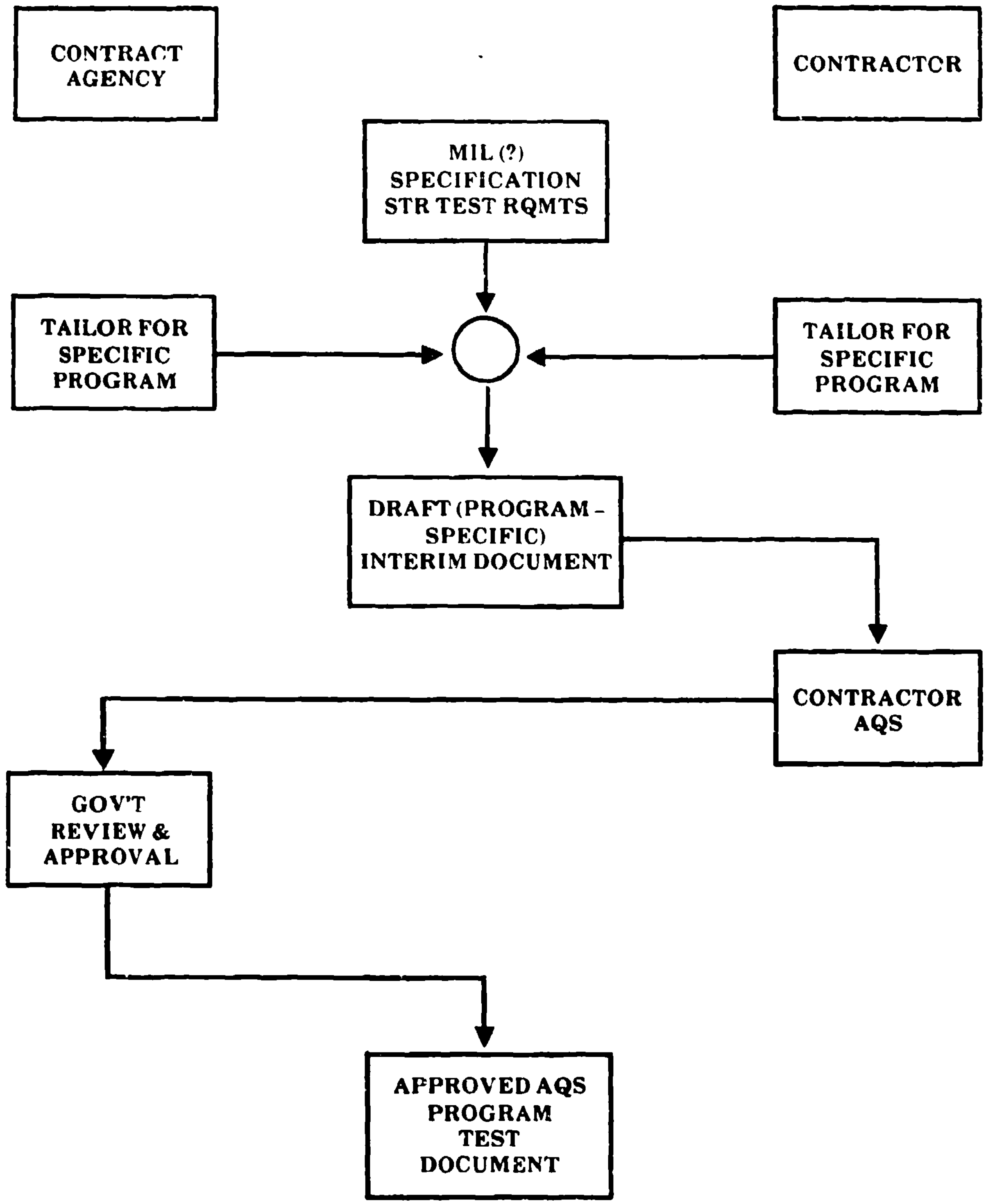

Figure 1. Program implementation.

1.4 Classification of Structure. Rotorcraft structure is classified as either "airframe" or "dynamic" structure. In general, the dynamic structure includes the rotors, rotor masts, control systems, and the drive system excluding gears, bearings and interconnecting shafts. The airframe structure includes all other structure. The specific components of these classifications, which include both metallic and nonmetallic structure, are listed in paragraphs 3.2, 3.3, and 3.4.

1.5 Category of Rotorcraft. Rotorcraft are categorized for the purpose of this specification as "transport/utility", "observation/scout", "attack", or "trainer". Rotorcraft configurations include, but are not limited to, single rotor, coaxial rotor, tandem rotor, tilt rotor, tilt wing, or compound (using turbofans, turboprops, or turbojets as auxiliary power sources).

2. APPLICABLE DOCUMENTS

(Document references will be added by the Army after other specifications related to HSIP have been identified and/or formulated.)

GENERAL

3. REQUIREMENTS

3.1 General Test Requirements. The following subparagraphs contain general test requirements and apply to all acquisition programs using this document.

3.1.1 Definitions.

3.1.1.1 Critical Test Condition. The design loading condition for which margins of safety indicate the structure is most likely to fail.

3.1.1.2 Load Factor. The ratio of a given load to a reference load. The reference load is usually the weight of the helicopter or the magnitude of the load when the helicopter is in static equilibrium. When employed, a subscript indicates the direction of the given load.

3.1.1.3 Limit Load or Limit Load Factor. A load or load factor which establishes a strength level for design of the rotorcraft and its components and is the maximum load within the flight envelope experienced during the life of the rotorcraft.

3.1.1.4 Ultimate Load or Ultimate Load Factor. The limit load or limit load factor multiplied by an ultimate factor of safety specified by the structural design criteria or reliability considerations, whichever is greater, for the specific acquisition program (normally 1.5).

3.1.1.5 Proof Load. A load that is of less magnitude than that which would induce permanent deformation or damage to the structure which is applied to provide test substantiation of strength, rigidity, or functional interference. A percentage of limit load will normally be specified as a minimum to be attained on actual flight hardware prior to rotorcraft first flight, or prior to use on any rotorcraft.

3.1.1.6 Structural Failure - Limit Load Tests. A structural test failure shall be the occurrence of one or more of the following events in metallic structure:

a. Evidence of yield.

b. Evidence of permanent set. Permanent set is any deformation which remains after release of load.

For composite structures, test failure at limit load shall be the occurrence of one or more of the following events:

a. Evidence of load induced damage (cracks, delaminations, disbonds, etc.) that would detrimentally affect the structural life of the component.

b. A change (increase or decrease) in structural stiffness in excess of dynamically acceptable limits. (These limits are determined by flutter or vibration level constraints.)

3.1.1.7 Structural Failure - Ultimate Load Tests. A structural test failure shall be the occurrence of one or more of the following events in metallic or composite structure:

a. Inability to sustain the applied test load for 3 seconds.

b. Measurement of gross area strains which exceed the environmentally and statistically reduced gross area design ultimate allowable.

3.1.1.8 Structural Failure - Repeated Load Tests. A test failure shall be the occurrence of one or more of the following events in metallic or composite structure:

a. Inability to sustain the applied test load.

b. Initiation and growth of damage to the size that would not meet the required residual strength load.

c. A change (increase or decrease) of structural stiffness in excess of dynamically acceptable limits. (These limits are determined by flutter or vibration level constraints.)

d. Initiation or growth of damage to the extent that would require maintenance action.

3.1.1.9 Residual Strength. This is the remaining load carrying capability of a structural component or assembly that has been subjected to repeated loads testing or of a damaged structural assembly. For fatigue tests, the required magnitude of the load shall be the maximum load that the structure might encounter during its lifetime. For damage tolerance tests, the required magnitude of the load is the maximum load that the structure might encounter during a specified inspection interval or during the aircraft's lifetime for non-inspectable structure. For both types of repeated load tests, the required residual load will include compensation for environ.. ental effects if the test is not conducted in the critical environment.

3.1.1.10 Material Variability. The term that refers to the statistical distribution in physical and mechanical properties due to variations of materials and processes. Material variability must be taken into account for both composite and metallic materials.

3.1.1.11 Critical Part. A structural part, assembly, installation, or production system with any critical characteristics whose failure would result in an unsafe condition in the completed product. Unsafe condition is defined as one which could cause loss o. the aircraft or any of its major components, loss of control, or a condition which could cause injury to occupants of the aircraft or ground support personnel.

3.1.1.12 Flight Safety Part. Any part, assembly, or installation where failure, malfunction, or absence could cause loss or serious damage to the aircraft and/or serious injury or death to the occupants or ground support personnel.

3.1.1.13 Repeated Loads Tests. Tests conducted under cyclic loading of a specimen, part, or full-scale component. Fatigue tests, durability tests, and damage tolerance tests are examples of repeated loads tests.

3.1.1.14 Economic Life. The life indicated by the results of the durability test program at which widespread damage occurs that is uneconomical to repair and, if not repaired, could cause functional problems affecting operational readiness.

3.1.1.15 Service Life. The specified time during which a part, component or aircraft can safely operate.

3.1.1.16 Damage Tolerance. The ability of a structure to resist failure due to the presence of flaws, cracks, or other damage for a specified period of unrepaired usage.

3.1.1.17 Durability. The ability of a structure to resist cracking (including stress corrosion and hydrogen induced cracking), corrosion, thermal degradation, delamination, wear, and the effects of foreign object damage for a specified period of time.

3.1.1.18 Fatigue. The ability of the structure to resist the initiation of damage under repeated loads for a specified period of time.

3.1.1.19 Coupon. This is a small test specimen that is used for evaluation of basic material properties or of properties of generic structural features, such as bonded or mechanically fastened joints.

3.1.1.20 Element. This is a representation of a more complex structural member, such as a skin, stringers, shear panels, sandwich panels, joints, or splices.

3.1.1.21 Subcomponent. This is a major three-dimensional structure which can provide complete structural representation of a section of the full structure, such as a stub-box, section of a spar, wing panel, wing rib, body panel or frames.

3.1.1.22 Component. This is a major section of the structure (hub, rotor blade, wing, fin, horizontal stabilizer) which can be tested as a complete unit to qualify the structure.

3.1.2 Test Objectives.

3.1.2.1 Static Test. Static tests of the airframe structure are conducted on a full scale airframe, major structural components, and/or elements. Static tests of dynamic components are conducted on critical parts.

The objectives of a static test program are to:

a. Verify that the design static strength and structural stiffness meet or exceed the required design loads

b. Substantiate design static strength and identify failure modes

c. Validate analytical methods that are used in substantiating the structure by analysis

3.1.2.2 Repeated Loads Tests. Repeated loads tests of the airframe structure may be conducted on a full scale airframe or on major structural components. Fatigue tests and damage tolerance tests of dynamic components are conducted on critical parts. Durability tests are conducted on parts where cracking, delamination, or other structural or material degradation such as wear or corrosion could result in excessive maintenance problems, functional problems affecting operational readiness, or significant cost impact.

The objectives of a repeated loads test program are to:

a. Locate any test-detectable fatigue or fracture critical areas of the structure not shown by the design analyses, and identify failure modes

b. Verify that the capability o[illegible]ucture is not degraded beyond acceptable limits during its specified service life w[illegible]bjected to the design spectra

c. Provide full scale test data to analytically establish the predicted service life and/or economic life of the structure

d. Provide a basis for inspection requirements

e. Provide a ready reference for comparison of test results with service use

f. Validate analytical methods to be used in substantiating the structure by analysis

3.1.2.3 Elastomeric Materials Tests. The objective of these tests is to verify that the elastomeric component is adequate for the intended application.

3.1.2.4 Flight Critical Bearings Tests. The objective of these tests is to verify the life/function of flight critical bearings.

3.1.3 Design Development and Verification Testing Approach for New Materials/Processes and Complex Designs. A building block approach to qualification shall be used for new materials and complex design configurations. The new materials are defined as those materials whose properties and design allowables are absent from current specifications. Complex design configurations are those structures that cannot be accurately analyzed with confidence or designs without previous service experience. The intent of these tests is to provide information for the component or structure design prior to final qualification tests, refer to Figure 2.

New materials will be evaluated for material properties, effects of material/process variability, environment, and defects. Nondestructive inspection methods, repeated load behavior, and component dependent properties will also be determined. This information will be used in determining the initial design concept.

Complex designs and new material design concepts will be evaluated for static and/or repeated load capabilities. Results from these subcomponent tests may influence the final design so that qualification by test and/or analysis may be accomplished in a timely manner.

3.1.4 Test Guidelines

3.1.4.1 Test Responsibilities. In the event any test herein is to be conducted by the Government, the contract shall so state. Otherwise all tests shall be conducted by the contractor.

3.1.4.2 Tests Performed by the Government. The Government test activity shall be responsible for conducting tests in accordance with the requirements of this specification.

3.1.4.3 Test Witnesses. As specified by the contract, the acquisition activity or local representative shall be notified to witness the test and certify the test record.

3.1.4.4 Test Documentation. As specified by the contract, test plans and test reports will be submitted for approval. All test data shall be retained as specified in the procuring contract.

3.1.4.5 Additional Tests. If the tests to be performed by the contractor, as required by this specification and/or the contract, are inadequate to prove that the rotorcraft structure meets the specified design requirements, the contractor or the acquisition activity shall propose amendments to the contract to include tests which will prove adequately that the structure meets the specified structural performance requirements.

3.1.5 Quality Assurance Requirements for Test Programs

3.1.5.1 Test Article Conformity. Each test article shall be conformed to the applicable engineering data, with all deviations reviewed and approved by the customer prior to test.

3.1.5.2 Test Setup Inspection. Each test setup shall be inspected as provided by the approved test plan for test article definition, test article location, test load application points, and test article reaction points.

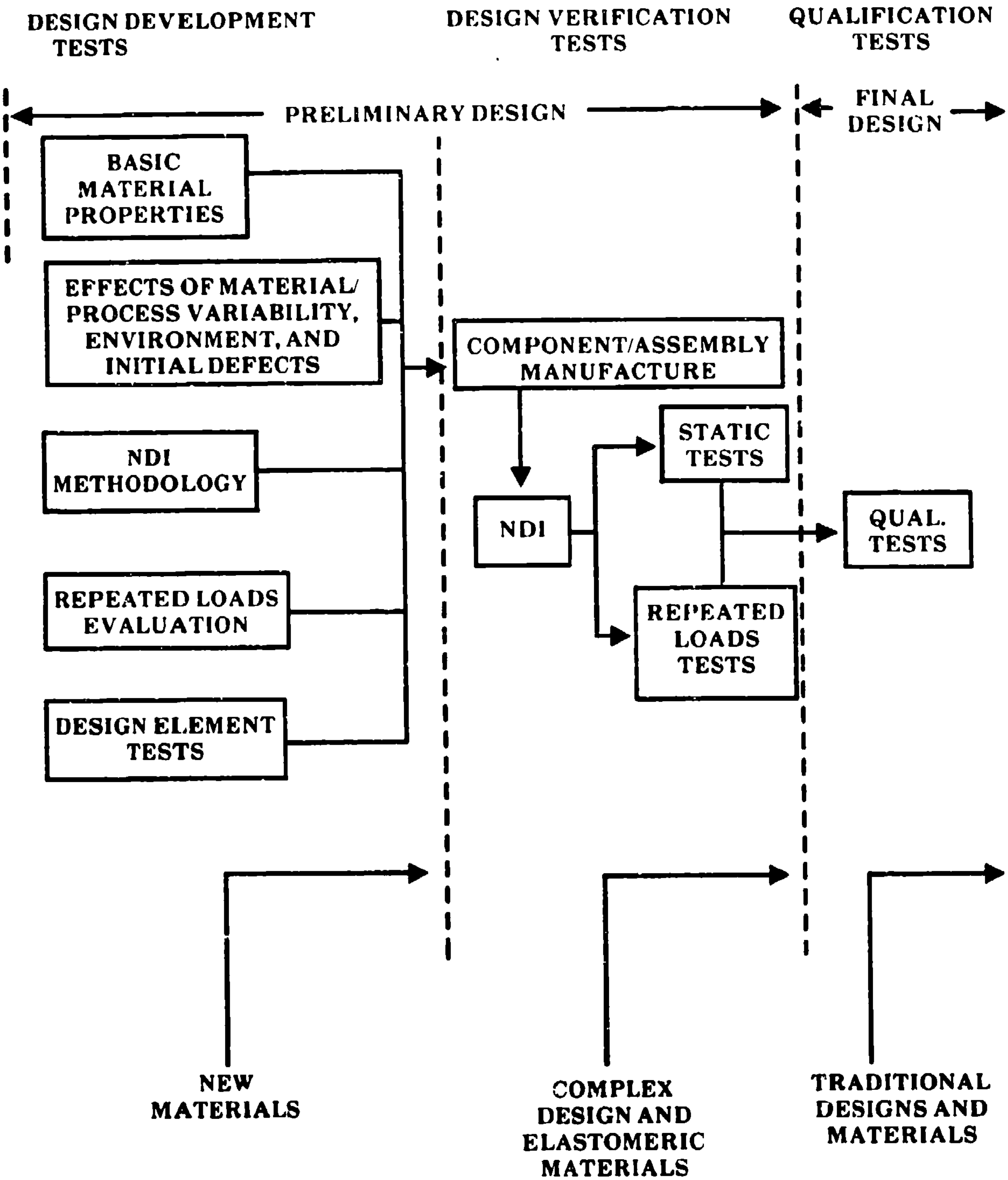

Figure 2. Building block approach to qualification.

3.1.5.3 Test Instrumentation Inspection. The test instrumentation shall be inspected for compliance with the approved test plan for location and orientation prior to the test.

3.1.5.4 In-Test Inspection. Test articles shall be inspected during test as defined in the approved test plan.

3.1.5.5 Post-Test Inspection. Test articles shall be inspected at the completion of scheduled testing in accordance with the approved test plan.

3.1.6 Test Articles. The contractor shall furnish test articles for performance of the tests. The following subparagraphs contain requirements which are common to all full scale test articles. To the extent practical, these requirements also apply to the element and subcomponent tests of paragraphs 3.2, 3.3, and 3.4.

3.1.6.1 Test Article Configuration. The full scale structural ground test articles shall be complete and representative of the flight article structure as follows:

a. Items such as fixed equipment and useful load, and their support structure may be omitted from the test structure provided the omission of these parts does not significantly affect the load, stress, strength, stiffness, or deflection of the structure to be tested; and provided the omitted parts would not be critically loaded in the test if they were to be installed.

b. All attachment holes for equipment, brackets, etc., and holes for routing of lines and wires, etc., must be included.

c. Substitute parts or test fixtures may be used provided they reproduce the effects of the parts for which they are substituted, and the structural integrity of the parts for which substitutions are made are demonstrated by supplementary test or analysis.

d. All structural modifications to the test articles that are necessary to accommodate the loading devices shall be designed in such a manner as to assure that the strength and rigidity characteristics of the modified structure will be equivalent to those of the actual structure.

e. Paint or other finishes that do not affect the structural performance (strength, rigidity, fatigue, durability, etc.) may be omitted.

f. Mechanical portions of the flight control systems shall be intact to the extent required to simulate and introduce or react test loads for the particular test program.

3.1.6.2 Load Application and Component Interaction. In a test of a structural component, the actual interaction between the component being tested and its adjacent components shall be existent or simulated. Structural components may be tested in a test fixture and/or loaded by substitute parts such that:

a. There is no possibility of interference or deflection that would result in improper loading of the component under test or adjacent components

b. The primary loads and reactions acting on the test component can be determined

c. All parts of the structure critical for the pertinent design condition can be tested and can be loaded simultaneously, if practicable.

3.1.6.3 Replacements and Repairs. Changes, adjustments, reinforcements, and repairs made in the test article to meet specified structural performance requirements shall be representative of those which will be incorporated in the flight test articles and production rotorcraft.

3.1.6.4 Use of Tested Parts. Parts of any test article that have been structurally tested shall not be used on any flight vehicle or any ground whirl test article unless specifically approved by the acquisition activity. An exception is made for parts that have been only proof-load tested.

3.1.6.5 Disposition of Test Articles. After completion of the authorized tests, the ground test articles shall be dispositioned in accordance with instructions issued by the acquisition activity. Prior to receipt of such instructions, ground test articles shall not be intentionally damaged or mutilated.

3.1.6.6 Use of Static Test Articles for Repeated Loads Tests. Static test articles shall not be used during subsequent fatigue/damage tolerant tests unless it can be shown analytically that the localized effects due to the static test loads do not affect the fatigue/damage tolerant characteristics of the test component.

3.1.7 Test Procedures

3.1.7.1 Test Loads. Initial structural testing shall be conducted using analytically derived design loads. Particular consideration shall be given to the possible magnitude and distribution of loads that can be achieved in rotorcraft having programmable flight control systems which govern, and are readily capable of altering, the flight characteristics of the rotorcraft.

3.1.7.1.1 Distribution of Loads and Load Combinations. The distribution of loads during the test shall duplicate, as close as practical, the actual distribution of the design loads. Loading conditions may be simplified for load tests. This may be accomplished by modifying the distribution of the loads applied to regions of the structure that:

a. are not critical in the loading conditions being simulated in the test, or

b. are identical in construction to other regions of the structure that are more highly stressed during the same or another test condition.

However, simplification of the method of loading shall not be such that unrepresentative permanent deformations or failures will occur. Where feasible, more than one loading condition may be applied simultaneously to different portions of the structure provided the interaction of the separate loading conditions does not affect the critical design loading on any portion of the structure. Loads resulting from the pressure differentials on pressurized portions of the structure shall be considered and, if critical, shall be simulated. This requirement is also applicable to the loads resulting from the pressurization of items of equipment such as fuel tanks or cells.

3.1.7.1.2 Test Loads - Static Tests. The load shall be applied in discrete increments to limit load with an adequate number of intervals for data collection to demonstrate the absence of yield in metallic structure, or load induced damage or change in stiffness in composite structure.

3.1.7.1.3 Test Loads - Repeated Loads Tests. The effects of applied load frequency and spectrum content (magnitude and location of high amplitude cycles) shall be accounted for in the repeated loads tests.

3.1.7.1.4 Environmental Effects. All environmental effects, natural or induced, which may produce significant reductions in strength of the structure or which may produce significant induced stresses shall be taken into account. These shall include, but not be limited to, moisture effects and temperature effects, such as high temperature or low temperature.

To account for the degradation of material properties due to environmental effects, structures constructed using environmental sensitive materials shall be tested in accordance with one of the following as applicable to each specific structure:

a. Environmentally Conditioned - Environmentally precondition the test article to the worst environmental condition for the critical failure modes and test to the critical design loads.

b. Reduced Strain Allowables - Test at laboratory environment for the critical failure modes to the critical design loads and demonstrate that the measured strains are less than the environmentally reduced design strain allowables for each test condition.

c. Increased Design Loads - Test at laboratory environment to factored design loads which have been adjusted to account for the degradation of properties due to environment for the critical failure modes.

3.1.7.1.5 Material and Process Variability. The contractor shall account for material and process variability during the qualification of structures when materials and/or processes are used for which current specifications do not define design allowables. Test programs shall be defined to provide the substantiating data to quantify the variability of material properties and manufacturing processes.

3.1.7.2 Safety Devices. When loads are applied in such a manner that they are not relieved when the rate of deformation of the structure of the test article increases rapidly (as when failure occurs), provisions shall be made to preclude excessive deformation or overloading of other parts of the structure, or excessive damage to the test article.

The method of testing shall include means of controlling the release of energy in the event of abrupt failure.

3.1.7.3 Premature Failure. If an indication of failure or actual failure occurs during a test, the cause of the indication or failure shall be investigated and the Government notified prior to continuing with or repeating the test and prior to corrective action on test articles or flight vehicles.

3.1.7.4 Failure Analysis. Each failure in a structural test shall be analyzed to determine the cause.

3.1.8 Test Measurements and Instrumentation

3.1.8.1 Test Measurements. All measurements recorded during structural tests shall be consistent with the test program objectives. Strain, deflection, temperature, and applied loads data are generally the required measurements. Measurements shall be made at representative points, and of sufficient quantity and accuracy to meet the test objectives. Suitable instrumentation shall be used to monitor applied test loads.

3.1.8.2 Measurement Recording. For static tests conducted in discrete load increments, measurements shall be made at each increment. For repeated loads testing, the test data shall be recorded on a time basis and with a data sampling rate sufficient to accomplish the required measurement objectives.

3.1.8.3 Test Instrumentation. The method of data acquisition and the type of recording devices for each test shall be defined in the test plan.

3.1.8.3.1 Installation. The contractor shall install all instrumentation used in performing the structural tests. All transducers and gage installations shall be properly located; be properly

mounted to assure valid measurements and freedom from extraneous excitations; be properly damped; and have frequency response consistent with test objectives. The installations shall not unduly affect the strain or frequency response of the instrumented component.

3.1.8.3.2 Instrumentation Effectivity. Instrumentation will be installed in critical areas as well as practical locations in test articles for different uses. Flight test article instrumentation shall use the static, fatigue, durability, dynamic drop, and dynamic whirl test article instrumentation as a base in order to provide a comparison of theoretical, tested, and actual flight strains, loads, and accelerations.

3.1.8.3.3 Calibration. Current calibration shall be required of all instrumentation (load cells, load links, deflection transducers, pressure transducers, calibrated structure, etc.) which require calibration for verification of performance. Calibration shall be performed, if practical, to the maximum range of excitation expected during the course of testing. Records of calibration shall be maintained to provide traceability for all instrumentation and instruments.

3.1.8.3.4 Instrumentation Documentation. A detailed description of all instrumentation (type and location) and recording devices and methods of calibration shall be defined in the test plan.

3.1.9 Test Article Inspections. Inspection programs shall be conducted as an integral part of the full scale repeated loads test program.

3.1.9.1 Design Inspections. Inspections shall be conducted at regular intervals, according to the schedule determined through analysis and during the test, and prior to the teardown inspection of 3.1.9.3. These inspections shall include, but not be limited to, those inspection procedures and intervals proposed for the fleet rotorcraft.

3.1.9.2 Special Inspections. The contractor shall define special inspections (both as to type and interval) to monitor the critical areas identified during design, to detect additional critical areas not previously identified, and to monitor crack growth rates.

3.1.9.3 Teardown Inspection. At the end of the full scale repeated loads test and/or residual strength tests, a teardown inspection shall be conducted. This inspection shall include disassembly and inspection of critical structural areas. Examinations shall be conducted to obtain data and to assist in the assessment of the initial quality of the components and the degree of compliance with the fatigue, durability, and damage tolerance design requirements.

3.1.10 Nondestructive Inspection (NDI) Proof Test. Tests shall be conducted to verify the NDI procedures, including those used during manufacture. These tests shall demonstrate that the NDI procedure developed for the part meets the design defect detection reliability requirements of the proposed design.

3.2 Airframe Test Requirements. This section applies to metallic and non-metallic rotorcraft airframe structures. The airframe structure includes such items as the fuselage, wings, tailboom, empennage, transmission mounts, engine mounts, nacelles/cowling, non-dynamic control system and control surfaces, and structural provisions for equipment, payload, cargo, and personnel.

The section is organized into four test sections: design development tests, design verification tests, airframe qualification tests, and post qualification tests. The first two sections are part of the building block approach, ref. 3.1.3, for new structural materials and may not be necessary should traditional materials and design concepts be used. Airframe qualification tests evaluate the integrity of the rotorcraft design. Post qualification tests are included for reference only, with the qualification tests used as a baseline for comparison.

The type of tests and number of test articles/specimens must be selected to support the chosen reliability methodology.

3.2.1 Airframe Design Development Tests. The contractor shall conduct tests for the purpose of establishing design concepts, providing design information, and providing early design validation. Airframe design development static and repeated loads tests should include coupon and element tests.

3.2.1.1 Element/Coupon Tests

a. New materials/processes. Material property tests shall be conducted to evaluate new materials and/or new production processes for which an established data base does not exist in current specifications. These may include tests for structural design allowables (tension, compression, shear, bearing, etc.), material behavior (stress-strain curves, elastic moduli, cyclic stress-strain curves, hysteresis curves, etc), repeated loads behavior (S-N tests, strain-life tests, crack/damage growth tests (da/dN), etc), fracture toughness behavior (threshold crack growth tests (ΔK_{th}), stress corrosion cracking (K_{Iscc}), etc.),and the effects of defects.

b. Compensation factor development program. The effects of material/process variability, operating environment (temperature, humidity, etc.) and initial acceptable flaws (specified induced damage; delaminations, voids, porosity, cracks, etc.) are to be accounted for in the qualification of the structure per paragraphs 3.1.7.1.4 and 3.1.7.1.5. Three methods of compliance are discussed in section 3.1.7.1.4. Testing shall be conducted to determine the effects of the above on structural design allowables, material behavior, and repeated loads capability.

c. Component NDI method development/verification. Methods of NDI shall be investigated to determine a production level of inspection which will, in turn, define the initial flaw sizes for compensation factor tests and applicable damage tolerance tests/analyses.

d. Repeated loads tests. Methods of repeated loads qualification for a new material/process will be evaluated in combination with the general material behavior and under the anticipated life loading of the designed structure (low-cycle, high cycle, or both). Testing may be performed at a coupon level for several failure modes, stress concentration factors (K_t), and surface treatments, or at the component level for anticipated loads. Test loads will account for the anticipated use of the structure (i.e., engine mount-high cycle, pressure cabin-low cycle). Analytical methods may include, but are not limited to, Miner's rule using stress-life and strain-life testing, damage tolerance using fracture mechanics testing, and total life approach. Qualification methods which propose increased test loads in lieu of a life scatter factor would also be evaluated.

3.2.1.2 Element Design Tests. Testing shall be conducted to determine the static and repeated loads behavior of component dependent design allowables. Static and repeated loads tests shall be conducted under anticipated loading to verify the proposed qualification methodologies. Components to be tested may include:

a. Structural attachments (splices and joints).

b. New fastening systems.

c. Component panels with discontinuities (cutouts).

d. Stability critical components.

e. Fittings.

f. Complex structural configurations.

3.2.2 Airframe Design Verification Tests. The contractor shall conduct tests for the purpose of timely verification of the structural performance capability of final or near-final structural designs of critical structural areas. Test components shall be fabricated using tooling and processes that are representative of production articles. Repeated loads tests shall be conducted to verify the method of qualification for the anticipated load spectrum. Static testing shall account for environmental and material variability using methods developed in 3.2.1. NDI methodology representative of production methods shall be performed on each test article.

Airframe components and structural assemblies to be tested should include:

a. Structural attachments.

b. Panels.

c. Fittings.

d. Assemblies.

e. Major airframe components.

3.2.3 Airframe Qualification Tests. The contractor shall conduct the following tests of full scale laboratory articles and full scale major assemblies in accordance with the test requirements specified herein as modified and amplified by the contract or supporting contractual documentation.

3.2.3.1 Proof Tests. The following proof tests shall be conducted.

3.2.3.1.1 Movable Surface Functional Proof Tests. Movable surfaces including control surfaces, wing pivots, pylon pivots, etc., shall be tested to determine satisfactory functioning within design operating limits. These tests shall be performed with the associated load induced deflection in the movable surface and airframe structure to which the movable surface is attached. These tests may be performed on suitable components up to limit load including associated deflections.

3.2.3.1.2 Movable Surface and Control System Strength Demonstration Proof Tests. Design limit pilot/computer effort shall be applied to each major control subsystem and design limit load shall be applied to the primary flight control surfaces. The applicable effort shall be applied on the major control subsystem up to the control surface attach points with simulated subsystem blockage at intermediate locations and at the control surface. Each major control subsystem shall be operated through its full travel while supporting design limit hinge moment. Limit system loads for fly-by-wire systems shall be used in lieu of maximum pilot effort loads.

3.2.3.2 Structure Capability Tests. Static tests of critical design conditions for the airframe shall be performed for the structural components/groups listed below. Examples of critical design conditions for the structure due to load conditions specified by the applicable structural design criteria are: Maximum up bending, down bending, positive and negative lateral bending, shear, torsion, pressurization (cabin and fuel cell), landing gear attachment loads, transmission support loads, maximum control system loads, etc.

a. Fuselage group tests.

b. Tailboom/empennage group tests.

c. Wing group tests.

d. Propulsion system (engine/transmission/drive system) support structure tests.

e. Control system tests (complete installation).

f. Miscellaneous tests.

Static design limit, ultimate and selected failing load tests shall be performed. The effects of non-detectable damage, environment and material/process variability shall be taken into account.

3.2.3.3 Life Assurance Tests. A life assurance qualification program shall require a combination of structural testing and analysis for primary load path structure and components of the airframe (including all critical parts and flight safety parts). Intent of the program is to establish/verify the structural/economic life of the airframe as required by the design specification. Methods of qualification may differ for each component and shall be proposed by the contractor. Accuracy of the results is dependent on the statistical probabilities and confidence of the material/structural capability (failure mode and strength values) and the anticipated load spectrum (constant amplitude oscillatory, flight-by-flight spectrum, frequency, and timely occurrence of residual stress/strain cycles).

3.2.3.3.1 General.

3.2.3.3.1.1 Methods of Qualification. Methods of qualification include, but are not limited to, fatigue (flaw/crack initiation), damage tolerance (flaw/crack growth), total life analysis (combining fatigue and damage tolerance) and durability. Testing may include coupon tests for material properties (for analysis), component tests, and/or full scale article tests. The life assurance methodology report shall include rationale for the method of qualification, number of test articles, magnitude of loads, and test duration (scatter factor) for each component.

3.2.3.3.1.2 Test Conditions. The test/analysis load spectrum for each component will account for all significant loads/environments experienced by that component throughout the life of the rotorcraft. Constant amplitude oscillatory loading rationale may be used for parts that do not experience a significant shift in mean and oscillatory values throughout their life (items such as engine mounts, drive systems supports, and skins subject to sonic fatigue loading). Spectrum loading shall be based on the mission profile requirements and shall be verified by comparison to a flight strain/load survey. Rationale may be used to tailor the load spectrum by omitting loads that can be shown to be insignificant to the life of the component. The effects of load frequency modification, clipping of high amplitude loads, and truncating of low amplitude loads must be accounted for by test/analysis.

Typical loads include, but are not limited to, rotor/drivetrain/propulsion induced loads, landing gear extension/retraction, landing/taxi/grounds loads, propulsion conversion loads, control surface and control system loads, maneuver loads, gust loads, cabin pressurization, fuel cell pressurization, and armament/stores delivery.

3.2.3.3.2 Airframe Component Fatigue Tests. S-N fatigue tests are typically conducted on parts subject to "high cycle" loading where crack/flaw initiation accounts for the majority of the total life of the part. Examples are rotor/engine/drive system supports and adjacent structure. Fatigue testing may include tests to determine the component fatigue strength (S-N) response for qualification analysis or tests of the component to a specific load spectrum. Component fatigue tests will be conducted per the approved test plan for each critical component to the appropriate load spectra. Inspection intervals shall be specified to enable detection of cracks/flaws. Fatigue tests for critical components are typically halted at the discovery of flaw initiation and the data used to specify field inspection intervals. Full scale components subjected to nominal spectrum loading shall continue to

be tested to evaluate damage growth (damage tolerance and total life analysis). Increased spectrum loads may be proposed to reduce the scatter factor (and test duration). Upon completion of the fatigue test the component shall be inspected and subjected to the critical load for residual capability verification.

3.2.3.3.3 Airframe Component Damage Tolerance Tests. Damage tolerance tests are typically conducted on parts subject to "low cycle" loading where crack/flaw growth accounts for the majority of the total life of the part. Component damage tolerance tests will be conducted per the approved test plan for each critical component to the appropriate load spectra. Manufacturing and service flaws shall be introduced per the test plan. Inspection intervals shall be specified to monitor growth of the cracks/flaws. Damage tolerance tests are typically halted when the flaw reaches critical size where residual strength could not be maintained. Test results shall be used to specify inspection and repair intervals. The flaws which have reached critical size may be repaired (if proposed) and testing continued. Upon completion of the test, the component shall be inspected and subjected to the critical load for residual capability verification.

3.2.3.3.4 Airframe Durability Tests. Durability tests shall be performed on components and structure susceptible to environmental degradation (corrosion, wear, thermal). Replacement lives, inspection intervals and economic lives shall be derived from test results by methods in the approved test plan.

3.2.4 Post Qualification Tests. Tests may be required after initial qualification and field deployment per a separate acquisition contract. (This section is included for reference purposes only.)

3.2.4.1 Surveillance Testing of Parts. Surveillance tests shall be conducted in support of the activity's Flight Safety Parts (FSP) program to verify that age and service have no detrimental effect on safe operation of the flight safety part within the defined structural life. Qualification tests may be used as baseline data for comparison.

3.2.4.2 Field Repair Qualification Tests. Repair qualification (verifying original strength, stiffness, etc.) may require tests to augment analyses.

3.3 Dynamic Components (Metallic) Test Requirements. The rotorcraft dynamic component metallic structures include such items as the rotor blades, fairings, hub, dynamic controls, pylon, rotor mast, and transmission housings. The type of tests and number of test articles/specimens must be selected to support the chosen reliability methodology.

3.3.1 Dynamic Components Design Development Tests. The contractor shall conduct tests for the purpose of establishing design concepts, providing design information, and providing early identification of failure modes and design validation. Additionally, the dynamic components design development static and repeated loads tests shall include, but not be limited to, coupon/element and component tests.

3.3.1.1 Coupon/Element Tests. In addition to the coupon/ element tests used to determine the basic material properties (design allowables) under the material test program, the coupon/element tests shall include, but not be limited to:

a. Material properties. Material properties tests shall include tests for structural design allowables, S-N tests, strain-life tests, cyclic stress-strain curve, hysteresis curves, fracture toughness, fatigue crack growth tests (da/dN), threshold crack growth tests (ΔK_{th}) and tests for stress corrosion cracking (K_{Iscc}).

b. Process evaluation. Tests shall be conducted to evaluate new manufacturing processes.

c. Fatigue and damage tolerance evaluation. Spectrum and/or constant amplitude S-N fatigue tests shall be conducted to evaluate the analytical methods chosen for the fatigue analysis (including Miner's rule for cumulative damage, residual stress, local stress and strain at stress risers), and to determine the effect of spectrum variation. These tests will be used as necessary to determine the adequacy of the analytical methods used to model load sequence, interaction effects, prestraining, etc. Also, spectrum fatigue tests shall be conducted to evaluate the analytical methods chosen for the fracture analysis, and to determine the effect of spectrum variation. These tests shall be used to verify the crack growth and retardation model.

d. Environmental effects. Tests shall be conducted to determine the effect of environment on static, fatigue, fracture, and crack growth material properties.

e. Fastener evaluation and joint configuration evaluation.

3.3.1.2 Component Tests. Component tests shall be conducted on new design concepts to evaluate:

a. Tooling and assembly processes.

b. Strength/stiffness.

c. Fatigue, durability, and damage tolerance.

d. Environmental effects.

3.3.2 Dynamic Components Design Verification Tests. The contractor shall conduct tests for the purpose of early verification of the static strength and repeated loads capability of final or near-final structural designs of critical structural areas. Test components/assemblies shall be fabricated using representative tooling and processes that are proposed for production articles. These tests shall include, but not be limited to:

a. Nondestructive inspection demonstration.

b. Tooling and assembly process confirmation.

c. Static strength and stiffness verification.

d. Repeated loads capability verification.

3.3.3 Tests for Elastomeric Materials. Endurance tests shall be conducted of the elastomeric material in the assembled configuration. Metal support structure shall be qualified separately, if necessary. The number and duration of tests shall be defined in the Airworthiness Qualification Specification (AQS). The elastomeric component shall be tested under a representative spectrum of loads, motions, and conditions. Environmental effects may be taken into account using coupon specimens.

3.3.4 Dynamic Components Qualification Tests. The contractor shall conduct the following tests of full scale laboratory articles and full scale major assemblies in accordance with the test requirements specified herein as modified and amplified by the contract or supporting contractual documentation.

3.3.4.1 Proof Tests. The following proof tests shall be conducted.

3.3.4.1.1 Movable Surface Functional Proof Tests. Movable surfaces including control surfaces, links, actuators, drive system, etc., shall be tested to determine satisfactory functioning within design operating limits. These tests shall be performed with the associated load-induced deflection in the

movable surface and rotorcraft structure to which the movable surface is attached. These tests may be performed on suitable components up to limit load including deflections.

3.3.4.1.2 Movable Surface and Mechanical Control System Strength Demonstration Proof Tests. Design limit pilot/computer effort shall be applied to each major dynamic control subsystem and design limit load shall be applied to the primary flight control system. The applicable effort shall be applied on the major control subsystem up to the control attach points with simulated subsystem blockage at intermediate locations and at the control attach point. Each major control subsystem shall be operated through its full travel while supporting design limit load. Limit system loads for fly-by-wire systems shall be used in lieu of maximum pilot effort loads.

3.3.4.2 Structure Capability Tests. The following static tests shall be performed.

3.3.4.2.1 Hub Assembly Static Tests. The hub assembly shall be subjected to combined static test loads of beam and chord moments, shears, and torsion. An axial load shall be applied to the hub assembly to simulate a centrifugal force. The hub assembly shall be static tested to design limit load, ultimate load, and failing load (or a minimum of TBD percent limit load). The beamwise, chordwise, and torsional stiffnesses may be determined by measuring rotational displacements due to unit load applications.

3.3.4.2.2 Rotor Blades Static Tests. Metallic rotor blades shall be static tested to design limit load, ultimate load, and failing load (or a minimum of TBD percent limit load). The beamwise, chordwise, and torsional stiffnesses of the inboard blade may be determined by measuring rotational displacements due to unit moment applications.

3.3.4.2.3 Pylon Assembly Static Tests. The complete pylon assembly shall be static tested to design limit load, ultimate load, and failing load (or a minimum of TBD percent limit load). Static stiffness tests of the complete assembly may be conducted with measurements of deflections and slope changes.

3.3.4.2.4 Rotor Blade Folding Mechanism Static Tests. The rotor blade fold mechanism shall be static tested to design limit load and ultimate load for the critical blade fold loading condition. At limit load, the deflections of the blade shall not cause interference with the rotorcraft structure.

3.3.4.2.5 Dynamic Controls Subsystem Static Tests. Control subsystem tests shall be those shown in Table 1. The cyclic and collective spring rates of the system may be determined by applying unit loads to the pitch links.

TABLE 1. DYNAMIC COMPONENTS CONTROL SUBSYSTEM TESTS

Number	Test	Loading Condition	Magnitude of Load	Special Requirements
a.	Longitudinal control system	Critical	Failing	Test each type of system. For each system that contains an irreversible mechanism, test the control system on each side of and including the irreversible mechanism.
b.	Lateral control system	Critical	Failing	
c.	Directional control system	Critical	Failing	
d.	Collective control system	Critical	Failing	
e.	Control systems of flight rotorcraft	Critical	Proof Load	

3.3.4.2.6 Mast Assembly Static Tests. The transmission housing, if loaded by rotor thrust or shear loads, complete with mast assembly shall be static tested to design limit load, ultimate load, and failing load (or a minimum of TBD percent limit load).

3.3.4.3 Fatigue, Durability, and Damage Tolerance Tests. Details of the type of fatigue, durability, and damage tolerance tests which are to be conducted will be given in the Airworthiness Qualification Specification (AQS) and may depend on the design methodology chosen and the reliability goals of the detail design requirements. If more than one type of test is required they may be conducted on the same test article, if applicable.

3.3.4.3.1 Dynamic Components Fatigue Tests. TBD full scale specimens each of the hub, rotor blades, rotor blade attachments, masts, dampers and supports, powered control actuators, and other rotor system/ dynamic components including transmission housings subjected to vibratory loadings shall be S-N or spectrum tested to failure or to a runout. A minimum of one specimen shall be tested prior to the start of flight testing and the remainder after the initial flight test loads are available. Manufacturing processes and environmental effects which may affect fatigue strength shall be evaluated.

The test loading shall be based on the mission profile as defined by the detail design requirements and the flight loads survey, if available. These mission profiles shall be combined with a distribution of significant parameters which may affect life such as cg, altitude, gross weight, load factor/ bank angle, yaw angle, sinking speed, roll angle, pitch angle, takeoff-landing speeds, rotor speeds, rotor-hub moments, control loads, torque variations, vibratory loadings, quasi-static loads, and all others pertinent to describing the repeated loads spectra to which the vehicle will be subjected. If spectrum tests are conducted, the spectrum may be truncated based on the results of S-N tests and strain-life tests.

Runouts/endurance limit need not be carried further than $10x10^6$ cycles for steel components, and $30x10^6$ cycles for aluminum, magnesium, and titanium components.

3.3.4.3.2 Dynamic Components Durability Tests. Tests shall be conducted to demonstrate compliance with the durability requirements of the design specification. These tests shall evaluate the ability of dynamic components to resist cracking or other structural or material degradation such as wear or corrosion which could result in excessive maintenance problems, functional problems affecting operational readiness, or significant cost impact.

The test loading spectrum shall be based on the mission profile as defined by the detail design requirements and the flight loads survey, if available. These mission profiles shall be combined with a distribution of significant parameters which may affect life such as cg, altitude, gross weight, load factor/bank angle, yaw angle, sinking speed, roll angle, pitch angle, takeoff-landing speed, rotor speeds, rotor-hub moments, control loads, torque variations, vibratory loadings, quasi-static loads, and all others pertinent to describing the repeated loads spectra to which the vehicle will be subjected. The spectrum may be truncated based on the results of S-N tests and strain - life tests.

The test environmental effects shall be accounted for in the full scale tests. Inspections shall be performed as a part of the durability tests. These inspections shall consist of design inspections, special inspections, and teardown inspection.

3.3.4.3.2.1 Rotor Blade Erosion Tests. Sand and rain erosion requirements of the rotor blade and/or erosion protection coverings shall be demonstrated.

3.3.4.3.2.2 Rotor Blade Folding Mechanism Durability Tests. The blade fold mechanism shall be tested under representative spectrum loads and motions. Environmental effects shall be taken into account.

3.3.4.3.3 Dynamic Components Damage Tolerance Tests. Tests shall be conducted to demonstrate compliance with the damage tolerance requirements of the design specification. The type and quantity of tests depend on the design concepts and the number of fracture critical areas. The types of tests shall include crack growth tests of single and multiple load path structure, residual strength tests, and life tests of multiple load path structure subsequent to single load path failure for crack arrest evaluation.

The test loading spectrum shall be based on the mission profile as defined by the detail design requirements and the flight loads survey, if available. These mission profiles shall be combined with a distribution of significant parameters which may affect life such as cg, altitude, gross weight, load factor/bank angle, yaw angle, sinking speed, roll angle, pitch angle, takeoff-landing speeds, rotor speeds, rotor-hub moments, control loads, torque variations, vibratory loadings, quasi-static loads, and all others pertinent to describing the repeated loads spectra to which the vehicle will be subjected. The spectrum may be truncated based on the results of S-N tests and strain-life tests.

The intent shall be to conduct damage tolerance tests of existing test articles/hardware. This may include use of components and assemblies of the design development tests and design verification tests, as well as the full scale static and repeated loads test articles. When necessary, additional structural components and assemblies shall be fabricated and tested to verify compliance with the damage tolerance design requirements.

3.3.4.4 Tests for Flight Critical Bearings. Flight critical rolling and sliding element bearings shall be tested to determine the bearing life. The number and duration of tests shall be determined by the contractor and proposed to the acquisition activity. The bearings shall be tested under representative spectrum loads and motions. Tests shall be conducted to determine the effect of environment on structural properties and performance. Satisfactory completion of predefined pass/fail criteria is required for qualification. Bearing life may be defined as wear, structural degradation, failure to perform the intended function, or combinations thereof.

3.3.5 Post Qualification Tests. Surveillance tests shall be conducted in support of the acquisition activity's Flight Safety Parts (FSP) program to verify that age and service have no detrimental effect on safe operation of the flight safety part.

3.4 Dynamic Component (Composite) Test Requirements. The rotorcraft dynamic component composite structures include such items as the rotor blades, fairings, hub, dynamic controls, pylon, rotor mast, and transmission housings. The type of tests and number of test articles/specimens must be selected to support the chosen reliability methodology.

3.4.1 Dynamic Components Design Development Tests. The contractor shall conduct tests to establish design concepts, provide design information, and provide early identification of failure modes and design validation. Additionally, the design development tests for composites are a part of the overall structural qualification procedure in that the test results are used in the interpretation of the full scale static and repeated loads test results. Design development tests range in complexity from coupon tests that are used to evaluate material and fastener behavior to full scale components. Static and repeated loads tests of dynamic components for design development shall include, but not be limited to, coupon/element and component tests.

3.4.1.1 Coupon/Element Tests. In addition to the coupon/ element tests used to determine the basic material properties (design allowables) under the material test program, the coupon/element tests shall include, but not be limited to:

a. Material properties. Material properties tests shall include tests for design allowables, in-plane and interlaminar fracture toughness, constant amplitude and spectrum S-N curves for in-plane loads, onset of delamination growth, and delamination growth rate. Specimen configuration shall include open hole, filled hole, loaded hole, and bearing specimens under static and repeated loads. Hole wear shall be evaluated.

b. Process evaluation. Tests shall be conducted to evaluate new manufacturing processes.

c. Fatigue and damage tolerance evaluation. Tests shall be conducted for fatigue and damage tolerance evaluation and shall account for the effects of environment including, but not limited to, temperature and moisture.

d. Environmental effects and scatter. Tests shall be conducted to determine the effect of environment on static, fatigue, fracture, and delamination growth material properties. Sufficient number of specimens shall be tested to develop meaningful statistical parameters.

e. Fastener evaluation and joint configuration evaluation.

3.4.1.2 Component Tests. Component tests shall be conducted on new design concepts to evaluate:

a. Tooling and assembly process investigation.

b. Strength/stiffness.

c. Fatigue, durability, and damage tolerance evaluation.

d. Environmental effects.

3.4.2 Dynamic Components Design Verification Tests. The contractor shall conduct tests for the purpose of early verification of the static strength and repeated loads capability of final or near-final structural designs of critical structural areas. Test components/assemblies shall be fabricated using representative tooling and processes that are proposed for production articles. These tests shall include, but not be limited to:

a. Nondestructive inspection demonstration.

b. Tooling and assembly process confirmation.

c. Static strength and stiffness verification.

d. Repeated loads capability verification.

e. Destructive inspection. Full scale critical dynamic components made of composite material shall be cut up and inspected to evaluate the components for manufacturing defects and to evaluate the manufacturing process. The number of components to be cut up shall be determined by the contractor.

3.4.3 Tests for Elastomeric Materials. Endurance tests shall be conducted of the elastomeric material in the assembled configuration. The support structure shall be qualified separately, if necessary. The

number and duration of tests shall be defined in the Airworthiness Qualification Specification (AQS). The elastomeric component shall be tested under a representative spectrum of loads, motions, and conditions. Environmental effects may be taken into account using coupon specimens.

3.4.4 Dynamic Components Qualification Tests. The contractor shall conduct the following tests of full scale laboratory articles and full scale major assemblies in accordance with the test requirements specified herein as modified and amplified by the contract or supporting contractual documentation.

3.4.4.1 Proof Tests. The following proof tests shall be conducted.

3.4.4.1.1 Movable Surface Functional Proof Tests. Movable surfaces including control surfaces, links, actuators, drive system, etc.,shall be tested to determine satisfactory functioning within design operating limits. These tests shall be performed with the associated load induced deflection in the movable surface and rotorcraft structure to which the movable surface is attached. These tests may be performed on suitable components up to limit load including deflections.

3.4.4.1.2 Movable Surface and Mechanical Control System Strength Demonstration Proof Tests. Design limit pilot/computer effort shall be applied to each major dynamic control subsystem,and design limit load shall be applied to the primary flight control system. The applicable effort shall be applied on the major control subsystem up to the control attach points with simulated subsystem blockage at intermediate locations and at the control attach point. Each major control subsystem shall be operated through its full travel while supporting design limit load. Limit system loads for fly-by-wire systems shall be used in lieu of maximum pilot effort loads.

3.4.4.2 Structure Capability Tests. The following static tests shall be performed.

3.4.4.2.1 Hub Assembly Static Tests. The hub assembly shall be subjected to combined static test loads of beam and chord moments, shears, and torsion. An axial load shall be applied to the hub assembly to simulate a centrifugal force. The hub assembly shall be static tested to design limit load, ultimate load, and failing load (or a minimum of TBD percent limit load). The beamwise, chordwise, and torsional stiffnesses may be determined by measuring rotational displacements due to unit load applications.

3.4.4.2.2 Rotor Blades Static Tests. Composite rotor blades shall be static tested to design limit load, ultimate load, and failing load (or a minimum of TBD percent limit load). The beamwise, chordwise, and torsional stiffnesses of the inboard blade may be determined by measuring rotational displacements due to unit moment applications.

3.4.4.2.3 Pylon Assembly Static Tests. The complete pylon assembly shall be static tested to design limit load, ultimate load, and failing load (or a minimum of TBD percent limit load). Static stiffness tests of the complete assembly may be conducted with measurements of deflections and slope changes.

3.4.4.2.4 Rotor Blade Folding Mechanism Static Tests. The rotor blade fold mechanism shall be static tested to design limit load and ultimate load for the critical blade fold loading condition. At limit load, the deflections of the blade shall not cause interference with the rotorcraft structure.

3.4.4.2.5 Dynamic Controls Subsystem Static Tests. Control subsystem tests shall be those shown in Table 1. The cyclic and collective spring rates of the system may be determined by applying unit loads to the pitch links.

3.4.4.2.6 Mast Assembly Static Tests. The transmission housing, if loaded by rotor thrust or shear loads, complete with mast assembly shall be static tested to limit load, ultimate load, and failing load (or a minimum of TBD percent limit load).

3.4.4.3 Fatigue, Durability, and Damage Tolerance Tests. Details of the type of fatigue, durability, and damage tolerance tests which are to be conducted will be given in the Airworthiness Qualification Specification (AQS) and may depend on the design methodology chosen and the reliability goals of the detail design requirements. If more than one type of test is required, they may be conducted on the same test article, if applicable.

3.4.4.3.1 Dynamic Components Fatigue Tests. TBD full scale specimens each of the hub, rotor blades, rotor blade attachments, masts, dampers and supports, powered control actuators, and other rotor system/dynamic components including transmission housings subjected to vibratory loadings shall be S-N or spectrum tested to failure or to a runout. A minimum of one specimen shall be tested prior to the start of flight testing and the remainder after the initial flight test loads are available. Manufacturing processes and environmental effects which may affect fatigue strength shall be evaluated.

The test loading shall be based on the mission profile as defined by the detail design requirements and the flight loads survey, if available. These mission profiles shall be combined with a distribution of significant parameters which may affect life such as cg, altitude, gross weight, load factor/bank angle, yaw angle, sinking speed, roll angle, pitch angle, takeoff-landing speeds, rotor speeds, rotor-hub moments, control loads, torque variations, vibratory loadings, quasi-static loads, and all others pertinent to describing the repeated loads to which the vehicle will be subjected. If spectrum tests are conducted, the spectrum may be truncated based on the results of S-N tests.

Runouts/endurance limit need not be carried further than 30×10^6 cycles for composites.

3.4.4.3.2 Dynamic Components Durability Tests. Tests shall be conducted to demonstrate compliance with the durability requirements of the design specification. These tests shall evaluate the ability of dynamic components to resist cracking, delamination, or other structural or material degradation such as wear which could result in excessive maintenance problems, functional problems affecting operational readiness, or significant cost impact.

The test loading spectrum shall be based on the mission profile as defined by the detail design requirements and the flight loads survey, if available. These mission profiles shall be combined with a distribution of significant parameters which may affect life such as cg, altitude, gross weight, load factor/bank angle, yaw angle, sinking speed, roll angle, pitch angle, takeoff-landing speed, rotor speeds, rotor-hub moments, control loads, torque variations, vibratory loadings, quasi-static loads, and all others pertinent to describing the repeated loads spectrum to which the vehicle will be subjected. The spectrum may be truncated based on the results of S-N tests.

The test environmental effects shall be accounted for in the full scale tests. Inspections shall be performed as a part of the durability tests. These inspections shall consist of design inspections, special inspections, and teardown inspection.

3.4.4.3.2.1 Rotor Blade Erosion Tests. Sand and rain erosion requirements of the rotor blade and/or erosion protection coverings shall be demonstrated.

3.4.4.3.2.2 Rotor Blade Folding Mechanism Durability Tests. The blade fold mechanism shall be tested under representative spectrum loads and motions. Environmental effects shall be taken into account.

3.4.4.3.3 Dynamic Components Damage Tolerance Tests. Tests shall be conducted to demonstrate compliance with the damage tolerance requirements of the design specification. The type and quantity of tests depend on the design concepts and the number of fracture critical areas. The types of tests shall include flaw growth tests of single and multiple load path structure, residual strength tests, and life tests of multiple load path structure subsequent to single load path failure for flaw arrest evaluation.

The test loading spectrum shall be based on the mission profile as defined by the detail design requirements and the flight load survey, if available. These mission profiles shall be combined with a distribution of significant parameters which may affect life such as cg, altitude, gross weight, load factor/bank angle, yaw angle, sinking speed, roll angle, pitch angle, takeoff-landing speeds, rotor speeds, rotor-hub moments, control loads, torque variations, vibratory loadings, quasi-static loads, and all others pertinent to describing the repeated loads spectra to which the vehicle will be subjected. The spectrum may be truncated based on the results of S-N tests.

The intent shall be to conduct damage tolerance tests of existing test articles/hardware. This may include use of components and assemblies of the design development tests and design verification tests, as well as the full scale static and repeated loads test articles. When necessary, additional structural components and assemblies shall be fabricated and tested to verify compliance with the damage tolerance design requirements.

3.4.4.4 Tests for Flight Critical Bearings. Flight critical rolling and sliding element bearings shall be tested to determine the bearing life. The number and duration of tests shall be determined by the contractor and proposed to the acquisition activity. The bearings shall be tested under representative spectrum loads and motions. Tests shall be conducted to determine the effect of environment on structural properties and performance. Satisfactory completion of a predefined pass/fail criteria is required for qualification. Bearing life may be defined as wear, structural degradation, failure to perform the intended function, or combinations thereof.

3.4.5 Post Qualification Tests. Surveillance tests shall be conducted in support of the acquisition activity's Flight Safety Parts (FSP) program to verify that age and service have no detrimental effect on safe operation of the flight safety part.